

Analysis of Potential Methane Hydrate Accumulations in a Block 857 Alaminos Canyon Well Site, Gulf of Mexico

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Abstract

The Gulf of Mexico has long been an area of extensive scientific study as a basin of geologic interest. The Gulf is in close proximity to the U.S. and the extensive gas hydrate that has been found during drilling operations there make it an attractive option for a potential continuous energy source long after gas and oil supplies have diminished. In this study, a well in the Alaminos Canyon Block 857 (API no. 608054002300), Gulf of Mexico, was examined using logging data, core records, and heatflow maps to determine if methane hydrate was potentially present in this area. Resistivity, API gravity, gamma ray, hydrocarbon fluorescence and bottom-simulating reflectors were all compared to seek markers that may suggest hydrate accumulations. This well, in an interval from 10240-10725 feet below the rig floor, shows the most promising indications of hydrate. Saturation values along this length averaged fifty-nine percent which was calculated using Archie's equation. After further analysis, gas condensate presence seemed more likely than hydrate but the saturation values calculated are still applicable. Future work should focus on repeating this process across other wells in Alaminos Canyon to determine the volume of methane hydrate that may exist, remaining careful to distinguish between hydrate and condensate concentrations. Ultimately, a distinct consensus on the amount of gas hydrate in the Gulf of Mexico will clarify the economic practicality of hydrates as an energy source.

Introduction

Methane hydrate has captured the interest of the scientific world for a long period of time but it is only recently, through the advancements of modern technology and well data, that it is feasible to determine how much methane hydrate exists and the significance of that quantity. Gas hydrate may be a potential energy source (Collett, 2002), a significant climate change variable (Archer, 2007), and a serious geohazard (Maslin et al., 2010). However, if the total amount of hydrate present in any given location isn't known, there's no telling the degree of its influence on any of these sectors (Sloan et al., 2008).

Gas hydrate has a cubic H₂O lattice with two common structure types, each varying in the amount of methane, ethane, or other gas molecules present (Kvenvolden, 1993). In structure type 2, diamond packing allows for larger gas molecules (such as propane) to be contained in the lattice. Structure type 1 is much more common in nature and most commonly contains methane gas (Sloan, 2003).

The Gulf of Mexico is one of the most well-studied basins in the world and there is plenty of seismic data that has already been collected in this region. This fact makes it a very attractive site for the possibility of future extraction or drilling projects. Most hydrate volume estimates in this area vary widely, however, as they are rarely based on physical data but rather on conceptual interpretations (Boswell et al., 2012). It is necessary to understand the formation, characteristics, and ideal stable environment of methane hydrate in order to interpret any data collected from cores.

Methane hydrate is generally produced in one of two ways: biogenically or thermogenically (Archer, 2007). Biogenic methane is a product of organic matter degradation by microorganisms and thermogenic methane is created by organic matter that has been thermally

altered at greater temperatures and pressures. The hydrate is typically found in outer continental margins in sand reservoirs along slopes or in permafrost. Once formed, it will appear as ice but the gases are actually held in its crystalline structure.

The temperature and pressure gradients are the main controls on hydrate stability. The gas hydrate stability zone is the area in the seafloor (below water column) where gas hydrate can exist in a stable state. Generally, a larger water column renders a thicker zone but this can vary largely depending on the temperature and salinity present in a particular site. If methane hydrate is removed from this stable environment, it will naturally release the gas it contains into the atmosphere. The likelihood of releasing large amounts of gas in small period of time is small but the effect they can have over extended periods of release could be detrimental (Archer, 2007). This is why there is concern for methane as a greenhouse gas and hydrate being a plausible source for serious global warming when it destabilizes.

Methane hydrate is also being studied not only for its risks but also for its benefits. The abundance of methane in hydrate surpasses the amount of all other natural hydrocarbon resources so it has realistic capabilities as a future energy source (Kvenvolden, 1988). On exploration seismic, hydrates create a bottom simulating reflector (BSR), due to their high compressional velocity, with the reflector indicating the transition between sediments with hydrates and those without (Lee, 2007). Methane hydrate also shows characteristically high resistivity. Examination of well logs to look for these features can provide a target area (or depth) that might hold hydrate. Determination of hydrate volume in-situ with these logs or analysis of core can give a much clearer and more precise value for the total hydrate in the Gulf of Mexico rather than a conceptual speculation.

In 2007, the Bureau of Ocean Energy Management (BOEM) lead an assessment of methane hydrate in the Gulf of Mexico by coordinating geophysical data along with the knowledge of preferred hydrate pressure and temperature controls. This assessment was based on a mass balance approach by using stochastic modeling to determine hydrate volumes. The in-situ methane hydrate was then estimated (see Figure 1) as a cumulative probability distribution, with a mean volume of 607 trillion m³ and 190 trillion m³ of that value assumed to be in sand reservoirs in high concentrations (Moridis et al., 2011). This method predominantly focused on gas that was biogenic in origin because the mass-balance model of thermogenic gas was found to be too convoluted and therefore disregarded. This can be seen as a fault of this method because approximately half of all vent gas in the Gulf may be thermogenic and thus likely a source for hydrate formation (Boswell, 2012).

Although reports, such as the BOEM assessment, are a great starting point, the model sits largely in presumption rather than hard evidence. Most gas hydrate data used had come from assessments of the geohazard risk involved rather than the energy resource possibilities. This changed, however, with the Joint Industry Project (JIP) Leg II Drilling Program that aimed to study gas hydrate as an economic resource (Boswell, 2012). All geological data that could be utilized, including geophysical interpretations and logging-while-drilling operations, were examined first to find perspective areas of hydrate in the same manner a company would explore for potential oil reservoirs. Specific indicators of gas hydrate, including increases in acoustic velocity, are regularly correlated with the gas hydrate stability zone. It has been found, however, that these velocity changes can also be produced by irregular sediment density, lithologic contrasts between water-saturated sands and muds, or porosity reduction. It could also be assumed that the opposite, no apparent velocity change, could also be a hydrate-bearing region.

Resistivity is the inverse of conductivity, meaning the opposition of current flow within a formation. Current flow generally occurs within pore space of a formation because water is generally held in this area and contains ions that allow for conductivity. Resistance to this flow suggests that something else besides water is in the pore space, most commonly a form of hydrocarbon. For this reason, gas hydrate shows a distinctive increase in resistivity in logging data and can be used to determine exact depths it may be present.

However, drilling expeditions are expensive, so for my thesis I will analyze petroleum industry well data and not data exclusively searching for hydrate. I focus on an industry well in Alaminos Canyon Block 857, Gulf of Mexico, (API no. 608054002300) for potential methane hydrate presence and also consider other possibilities, such as gas condensate. The data I will evaluate were released by Shell when exploring for oil. The cores are not currently available and cannot be evaluated as a cross-reference with the seismic; however, some core reports will be used. Resistivity logs were utilized, along with Archie's equation, to find a value for the overall methane hydrate present in this well site. Ultimately, other scientists should continue this work in order to find a volume estimate for all wells in Alaminos Canyon and, more importantly, the rest of the Gulf of Mexico. A complete volume estimate for this region can provide an assessment of the economic viability of marine hydrate deposits for the United States and other local countries that could reap the benefits in the future.

Methods

In order for methane hydrate to be considered as an energy source, the actual amount in any region must be first determined. Spikes in resistivity logs can be used to define certain sections (depths) where methane hydrate may exist. The well of focus (API # 608054002300),

seen in Figure 2, showed distinctive increases in resistivity at depths of 10240-10725 feet, as seen in log. This increase is visible by examining the deflection of the Phase Electromagnetic Phase Resistivity (EWR) line to the right of a defined, water-saturated baseline, R_o . The baseline chosen is defined by the vertical red line shown in Figure 3, because it displayed the most consistency throughout the length of the log.

Seven points along the Shallow Phase EWR line, numbered 1-7 increasing in value as depth increases (Figure 3) will be used to determine hydrate saturation at the cooresponding depths. The gamma ray log is also visible on the far left column of Figure 3 (bolded, not dashed) and was utilized to determine whether the section of interest was predominantly sand or clay-rich. The log showed no substantial deflection in gamma ray from 10240-10725 feet, suggesting a sand-rich section. For hydrate that exists in sand-rich sections, the hydrate saturation can be directly interpreted as the volume. It is only when hydrate potentially exists in clay-rich sections that other steps must be taken to determine the volume from the saturation but for the purposes of this study, these are not an issue (Cook, 2010).

Archie's equation has been used in the gas and oil industry for decades but is also useful for the determination of other hydrocarbon saturations, such as methane hydrates (Cook, 2010). Archie (1942) derived this equation to find hydrocarbon saturation within brine-filled sand and I chose to utilize this equation for the well of interest.

$$S_h = 1 - \sqrt{\frac{R_o}{R_t}}$$

S_h is the saturation of the hydrate, R_o designates the resistivity value along the baseline I created ($1\Omega\cdot m$) and R_t is the measured resistivity – in this case, points 1-7 from Figure 3.

Depth points 1-7 all had very different resistivity values to avoid skewing the mean saturation value across the range 10240-10725 ft. Points 1, 3, and 5 were placed at their current

locations because those areas have some of the highest resistivity values along the range of interest. Points 2 and 4 both showed resistivity values significantly lower and closer to R_o . Points 6 and 7 have resistivity values roughly in the middle of R_o and the maximum measured resistivity. The points were selected to create variety in the resistivity values and therefore the saturation values. Averaging all the saturation values leads to a more realistic mean saturation across this area. The resistivity at points 1-7 and the calculated hydrate saturations can be seen in Table 1. By averaging all the saturation values, a mean saturation across the full interval was calculated as 59%. Although there were other small sections that displayed electrical anisotropy in more clay-heavy sections, which is indicative of potential hydrate (Cook et al., 2010), the thickness of the anomalies were insignificant enough to be ignored for the purposes of this study. As described previously, this saturation does not necessarily denote the existence of hydrate at that location. This saturation value could instead be the concentration of methane condensate in the formation.

Discussion

Fifty-nine percent hydrate saturation across a section 485 feet is a significant potential resource. A comparison of this value to other saturations in surrounding wells of Alaminos Canyon will give a clearer representation and more accurate volume estimate for potential hydrate in the region.

Variability within the data can be created by various forms of hydrocarbons that may share similar properties with one another but are ultimately of a different composition or maturity. Originally, the resistivity data collected from well number 608054002300 seemed like a promising indicator for methane hydrate accumulated at 10240-10725 feet. However, the

acoustic velocity and density do not fluctuate through the well of interest in Alaminos Canyon Block 857 which led to an exploration of the possibility of another hydrocarbon. (William Shedd, Personal Communication, February 27, 2013). After evaluation and consultation with William Shedd and Matthew Frye, scientists working for BOEM, the concept of methane condensate accumulations became a viable option to investigate.

Gas condensate is created when a pool of hydrocarbons is exposed to the appropriate temperature and pressure gradients and evaporates. This evaporate travels upward, driven by pressure through faults or fractures, and eventually condenses back into a liquid at lower pressures (Zhang, 2011). Confusion can arise with condensates because they have a variable composition when created by evaporative fractionation, rather than from a single-source origin. Evaporative fractionation involves the physical separation of a gas-condensate cap from its associated oil (Silverman, 1963). Almost all of the condensate in the Gulf of Mexico may be created in this way, which accounts for the wide variety of hydrocarbon compositions in this region (Thompson, 1988).

As condensate became a feasible option to account for the variable data, other factors at this site were then examined. Shedd and Frye found the BSR was above the targeted depth meaning the depth range examined in this particular well is likely not within the gas hydrate stability zone. Blue fluorescence was emitted from sidewall core samples (see Figure 4) which is a typical sign of gas condensate. Shorter wavelengths in the visible spectrum (violets) are associated with higher API (American Petroleum Institute) gravities, as is the case here (Riecker, 1962).

Once the possibility of condensate was considered, I was interested in determining why hydrate did not seem likely in an area that was thought to be within the calculated stability zone.

One possibility is there must have been more thermal alteration occurring in this area, causing a higher geothermal gradient. GeoMapApp was used to display heatflow across a map of the Earth and observe how the Gulf of Mexico compared to the rest of the world. The well “dots” in this region are larger and an almost yellow shade which clearly demonstrates the higher heat flow here compared to the majority of the surrounding area (Figure 5). The area just to the west of Mexico (Gulf of California) with the unusually high heat index is associated with the transition from continental rifting to seafloor spreading at this area (Prol-Ledesma et al., 2012). With the exception of this area, the majority of the region surrounding the Gulf of Mexico does not seem to exhibit heatflow values as high as those in the Gulf.

The gradients used to determine the Gas Hydrate Stability Zone (GHSZ) were standard for all ocean basins and did not account for variations in heat flow across a particular region. The gradient used would create a larger stability zone because hydrate exists in lower temperature and higher pressure areas, and the data do not account for the unusually high temperatures (See Figure 5) in Alaminos Canyon. Standardizing temperature across all basins could account for the discrepancy between the BSR reflector-determined stability base and the base found through geothermal data.

To determine which methane composition is more likely to be found in the depth of interest, it is necessary to consider both hydrate and condensate. Light liquid hydrocarbons can dissolve in natural gases more easily than the heavy ones which is why the density of condensate generally ranges from 0.72 g/cm³ to 0.81g/cm³ (Zhang et al., 2011). The core data for this well (Courtesy of Shell, 2004) can help additionally provide a wider spectrum of information so one may come to an accurate conclusion about the composition. Table 2 shows the core data for a partial section of the depth of interest. The API gravities are displayed on the right side and range

35-49°, which suggests condensate. Typical API gravity values for condensate were originally determined by laboratory studies on the alteration of gas and oil to condensate (Timmins et al., 1978). Examining API gravity, resistivity, acoustic velocity, hydrocarbon fluorescence, and heatflow all point to condensate. While I first calculated gas saturation in this well for natural gas hydrate, the calculations are also valid for gas condensate.

Conclusion

Well number 608054002300 in Alaminos Canyon Block 857 originally seemed like a clear choice for methane hydrate exploration in the future after examination of the resistivity logs for this well. However, after analysis of other logs, composition, heat variables, etc. it has been found that gas condensate in this well is a more likely. The lack of acoustic velocity increase through the layer of interest and the gas hydrate stability base existing above this layer are the clearest indicators of condensate. The methods utilized in this study can easily apply to future analysis of other wells or blocks within the Gulf of Mexico and to eventually understand exactly how much hydrate is in this region.

Future Work

Other studies in this region should utilize pressure cores from the wells because, when extracted appropriately, can lead to highly accurate estimates of the hydrates present in that area (Cook, 2010). Analysis of core from the GHSZ, rather than deeper into the well, would be beneficial to the continued study of hydrates in this region. Access only to cores that may not cover the full spectrum of the stability zone is a hindrance to accurate volume estimates.

Continued study of condensates, a lesser known hydrocarbon, is essential in order to avoid confusion in the future.

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Figures

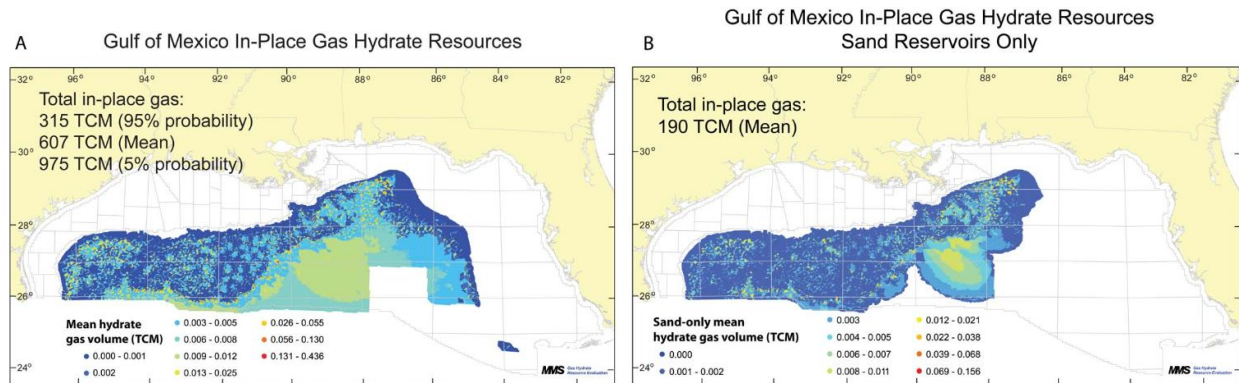


Figure 1. Gas hydrate volume estimates in the Gulf of Mexico (Figure 1 of Moridis et al., 2011)



Figure 2. Location of target well in Alaminos Canyon, Gulf of Mexico.

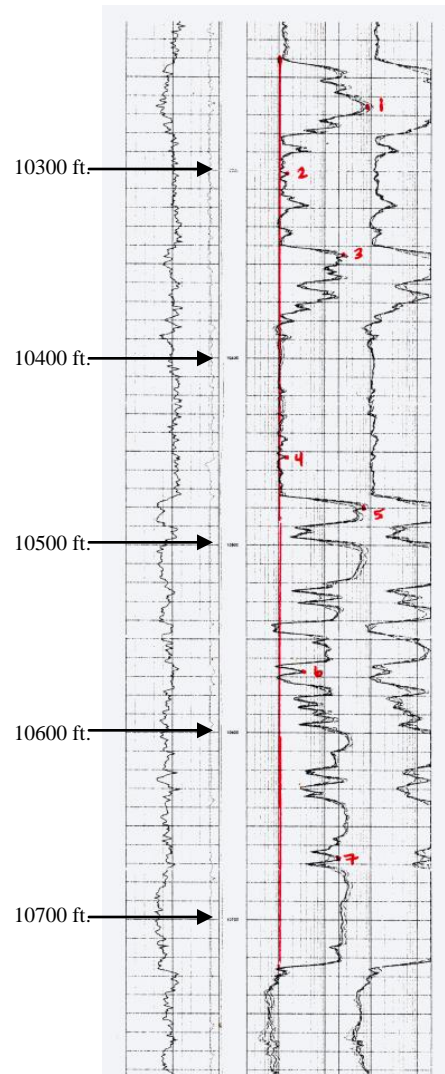


Figure 3. Resistivity well log along depth of potential hydrate concentrations. Baseline defined by vertical red line. Points 1-7 used for saturation determination.

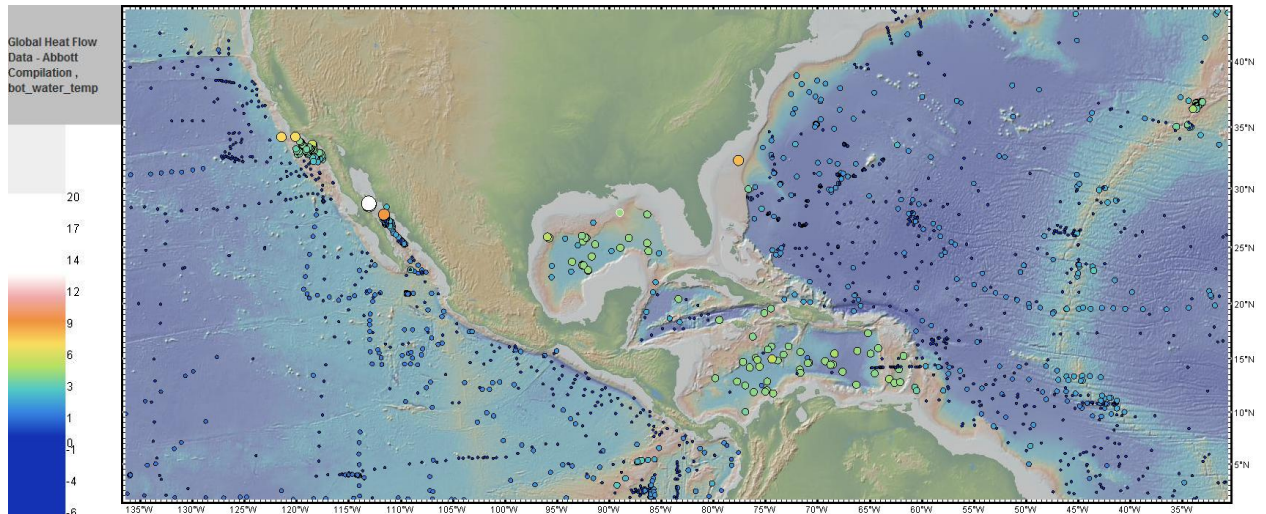


Figure 5. Heatflow graphed from well data throughout the world. Color and size of well “dots” indicative of heatflow values (GeoMapApp).

Tables

Point #	1	2	3	4	5	6	7
Depth (ft.)	10226	10302	10345	10453	10480	10567	10667
Measured Resistivity (R_t) [$\Omega \cdot m$]	80	1.5	25	1.5	70	3.0	20
Water-saturated, Baseline Resistivity (R_o) [$\Omega \cdot m$]	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Hydrate Saturation (S_h)	89%	18%	80%	18%	88%	42%	78%

Table 1. Depth, R_t , R_o , and S_h of the formation along depth of interest (10240-10725 ft.)

In. Rec.	Sample Depth Feet	Permeability mD	Porosity %	Pore Volume Saturation		Prob Prod	Bulk Volume Saturation		Comb. Gas	Crit. Water %	QA Factor	Core Lithology
				Oil %	Water %		Oil %	Gas %				
1.5	10495.0											Sd vf-fg vsity w/sh lam bt yl-bl flu
1.5	10498.0											Silt vshy lam ft spts flu
0.0	10501.0											Misfire
1.0	10503.0											Sd f-vfg ssity bl flu
1.8	10505.0											Shale w/thn silt lams vft flu
0.0	10507.0											Misfire
1.3	10509.0											Sd f-vfg ssity bl-wh flu
1.0	10512.0											Sd f-vfg ssity ft bl flu
1.3	10515.0											Sd f-vfg vssity bl-wh flu
1.9	10518.0											Sd f-vfg ssity bl-wh-yl flu
0.0	10521.0											
1.3	10524.0											Sd vf-fg slty sshy bt yl-wh flu
2.0	10527.0											Shale vsity ft bl flu stk flu
0.8	10530.0											Sd f-vfg ssity bl-yl-wh flu
1.5	10533.0	700.0	29.5	42.4	36.4	(4)	12.5	6.3	0	0	2sm	Sd f-vfg ssity yl-bl flu 49 api
1.5	10536.0											Sd vf-fg ssity-slty bl-yl flu
1.5	10538.0											Sd vf-fg slty w/sm sh incl yl-bl flu
1.0	10542.0	2400.0	33.3	50.9	12.9	(4)	16.9	12.0	0	0	2s	Sd fg ssity yl flu 44 api
0.8	10545.0											Sd vf-fg ssity bl flu
1.8	10549.0											Shale slty yl spts flu
1.8	10551.0											Silt shy lam bt yl-bl stkd flu
1.3	10553.0											Shale slty vft flu
1.3	10558.0	950.0	31.6	55.5	15.2	(4)	17.5	9.3	0	0	2s	Sd f-vfg slty yl flu
1.5	10560.0											Sd vf-fg slty ft bl flu
1.3	10563.0	1050.0	33.2	51.4	17.4	(4)	17.1	10.4	0	0	2s	Sd f-vfg slty bt yl flu 35 api
1.5	10566.0											Sd vf-fg slty sshy yl-bl flu
1.3	10569.0											Sd vf-fg ssity ft bl flu
1.3	10576.0	99.0	28.2	43.0	39.8	(4)	12.1	4.9	0	0	2s	Sd vfg vsity brnz flu 49 api
1.8	10579.0											Shale slty yl-bl stkd flu
1.5	10586.0	880.0	31.2	43.3	39.0	(4)	13.5	5.5	0	0	2s	Sd f-vfg slty sshy bl flu 49 api
1.0	10588.0	730.0	32.1	58.6	19.1	(4)	18.8	7.1	0	0	2s	Sd f-vfg slty sshy bl flu 49 api
1.5	10591.0											Sd vf-fg vsity sshy ft bl flu
1.3	10595.0	535.0	29.9	50.8	33.6	(4)	15.2	4.7	0	0	2s	Sd vfg slty sshy bl-yl flu 45 api

Table 2. Core data from well of interest (API no. 608054002300) over interval of depth that suggests possible hydrate present (Courtesy of Shell).

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